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NAVAL POSTGRADUATE SCHOOL

Monterey, California

THESIS

PERFORMANCE MEASURES FOR
U.S. PACIFIC FLEET
SHIP INTERMEDIATE MAINTENANCE ACTIVITIES

by

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September, 1992

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Unclassified
SECURITY CLASSIFICATION OF THIS PAGE

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION
UNCLASSIFIED

1b. RESTRICTIVE MARKINGS

2a. SECURITY CLASSIFICATION AUTHORITY

2b. DECLASSIFICATION/DOWNGRADING SCHEDULE

3. DISTRIBUTION/AVAILABILITY OF REPORT
Approved for public release; distribution is unlimited

4. PERFORMING ORGANIZATION REPORT NUMBER(S)

5. MONITORING ORGANIZATION REPORT NUMBER(S)

6a. NAME OF PERFORMING ORGANIZATION
Naval Postgraduate School

6b. OFFICE SYMBOL
OR

7a. NAME OF MONITORING ORGANIZATION

6c. ADDRESS (City, State, and ZIP Code)
Monterey, CA 93943-5000

7b. ADDRESS (City, State, and ZIP Code)

8a. NAME OF FUNDING/SPONSORING ORGANIZATION

8b. OFFICE SYMBOL

9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER

8c. ADDRESS (City, State, and ZIP Code)

10. SOURCE OF FUNDING NUMBERS

PROGRAM ELEMENT NO.	PROJECT NO.	TASK NO.	WORK UNIT ACCESSION NO.

11. TITLE (Including Security Classification)
PERFORMANCE MEASURES FOR U.S. PACIFIC FLEET SHIP INTERMEDIATE MAINTENANCE ACTIVITIES

12 PERSONAL AUTHOR(S)
McLay, Deidre Loreen

13 TYPE OF REPORT
Master's thesis

13b. TIME COVERED
FROM TO

14. DATE OF REPORT (Year, Month, Day)
1992, SEPTEMBER

15. Page Count
75

16. SUPPLEMENTAL NOTATION
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

17. COSATI CODES

FIELD	GROUP	SUB-GROUP

18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)
Performance, Efficiency, Productivity, Measure of Effectiveness, Intermediate Maintenance Activity

19. ABSTRACT (Continue on reverse if necessary and identify by block number)

The subject of this thesis is performance measures for U.S. Pacific Fleet Ship Intermediate Maintenance Activities (IMAs). It examines measurement data collected by the Maintenance Resource Management Systems (MRMS) and the Monthly IMA Utilization Report. Also, new timeliness measures of effectiveness are defined. The purpose of the study is to present, in one document, a description of all currently collected IMA performance measures, recommendations for other performance measures, and a statistical analysis of the performance measures to determine if they show performance differences between the Intermediate Maintenance Activities.

20 DISTRIBUTION/AVAILABILTIY OF ABSTRACT
X UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC

1a. REPORT SECURITY CLASSIFICATION
Unclassified

22a. NAME OF RESPONSIBLE INDIVIDUAL
Dan C. Boger

22b. TELEPHONE (Include Area Code)
(408)646-2607

22c. OFFICE SYMBOL
OR/Bo

DD Form 1473, JUN 86

Previous editions are obsolete.
S/N 0102-LF 014-6603

SECURITY CLASSIFICATION OF THIS PAGE
Unclassified

Performance Measures for U.S. Pacific Fleet
Ship Intermediate Maintenance Activities

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Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1992

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ABSTRACT

The subject of this thesis is performance measures for U.S. Pacific Fleet Ship Intermediate Maintenance Activities (IMAs). It examines measurement data collected by the Maintenance Resource Management System (MRMS) and the Monthly IMA Utilization Report. Also, new timeliness measures of effectiveness are defined. The purpose of the study is to present, in one document, a description of all currently collected IMA performance measures, recommendations for other performance measures, and a statistical analysis of the performance measures to determine if they show performance differences between the Intermediate Maintenance Activities.

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I. INTRODUCTION

A. WHY MEASURE PERFORMANCE ?

It is often true that measurement data is collected and then nothing is done with the data. If measurement data isn't used for something, then collecting it is a waste of time, effort, and resources. There must be a reason for collecting performance information about Intermediate Maintenance Activities.

Perigord writes,

> "The purpose of measurement is to find evidence of any variation from the negotiated specifications. The role of measurement is to identify possible improvements and to indicate where to initiate action on failures. Above all, measurement should be a potent vehicle of success." [Ref. 1]

"Success" is definitely a goal of Intermediate Maintenance Activities (IMAs). As elements of the United States Navy, they must perform their mission well at all times to ensure military readiness.

The determination that an IMA is performing its mission well is accomplished through measuring its performance. Performing "well" can mean many things, including performing effectively and efficiently.

Changes in the military due to the collapse of the Soviet Union and other world events may require that some ship maintenance practices be altered. In 1990, U. S. Pacific Fleet Staff members agreed that the following assumptions regarding future Pacific Fleet maintenance trends were valid:

- Less resources available for maintenance,
- Shorter repair and modernization periods,
- More technically complex platforms,
- Infrastructure changes, such as base closures and consolidation of facilities,
- Growth of Intermediate level workload,
- Greater customer awareness of quality, and
- Increased emphasis on measurement.[Ref. 2]

Meaningful measurement data for Intermediate Maintenance Activity performance is clearly desirable. However, it has been and continues to be difficult to obtain.

Intermediate Maintenance Activities (IMAs) came into being in a rather hit or miss kind of way. The IMAs were created in their earliest form as a solution to a manpower sea duty and shore duty rotation problem that resulted from the end of the United States' involvement in the Viet Nam War. Their maintenance mission was defined after the fact. The IMAs were not created in response to an existing maintenance need. No formal performance measurement methods were defined.

Several observers have commented on the methods of performance evaluation that were developed informally. Christopher Moe wrote in 1985,

> "At SIMA Norfolk first line managers evaluate shop productivity on professional "gut feeling". Characteristics that support this judgmental estimation focus generally on personal motivation of shop personnel, skill acquired through on-the-job experience, and training received through technical schools. Most of these same managers based considerable weight on their individual ability to gauge productivity through visual evaluation of shop activity. This visual perception was further supported by each manager's knowledge of jobs in progress and projected

completion dates required to meet the ship's departure from the repair availability." [Ref. 3]

William Marshall gave a simpler description. He listed the following methods used at a Shore Intermediate Maintenance Activity (SIMA) for productivity measurement:

- Management by walking around,
- Observation of the parking lot technique, i.e. if the parking lot is empty early in the day not enough work is being done,
- Completion rate,
- Number of productive manhours expended,
- Amount of shop overtime,
- Rework percentage, and
- Waterfront reputation.[Ref. 4]

Obviously, these are subjective measurement methods, difficult to record and analyze. More quantitative, repeatable techniques are needed to obtain meaningful measurement data. Such data are needed to identify possible improvements and to identify and correct failures.

B. THESIS OVERVIEW

This thesis is organized into seven chapters. This introduction is Chapter I. Chapter II is a description of Navy ship maintenance. Chapter III contains a discussion of various terms used in performance measurement. Current Intermediate Maintenance

Activity performance measures are examined in Chapters IV and V. Chapter VI proposes a new performance measure and Chapter VII contains conclusions and recommendations.

II. NAVY SHIP MAINTENANCE

A. BACKGROUND

Ships are complex structures that require constant care and upkeep. They operate at sea, a harsh and unforgiving environment; an uncared for ship will quickly deteriorate and fail its user. Modern warships have the additional complexity of advanced weapons systems and gas turbine propulsion plants. Such Navy vessels must be able to respond to crises at any time in addition to performing routine deployments and exercises. There is no place for unkempt, broken down ships in the United States Navy. To help ensure that the ships of the fleet will be ready when called upon, the Navy has an extensive ship maintenance program.

The Navy ship maintenance program is designed to keep ships at "an adequate level of material condition to maximize their required operational availability to the Fleet Commanders" [Ref. 5]. In other words, the goal of the maintenance program is to keep everything in the ships of the Navy in proper working order and in proper condition as much as possible. "Downtime" for any system or component is to be minimized.

The Navy ship maintenance program has three levels, each requiring a different degree of capability. The levels are organizational, intermediate, and depot. Each level is defined below.

1. Organizational Level

The first level of maintenance is the organizational level consisting of the ship itself and the sailors on board the ship. Organizational level maintenance is that corrective and preventive maintenance accomplished by the ship's crew. The work is a blend of equipment operation, condition monitoring, planned maintenance actions and repair ranging from simple equipment lubrication to component change out and, in some cases, complete rework in place. [Ref. 6]

2. Intermediate Level

The second level of maintenance is the intermediate level consisting of Tenders, Repair Ships, Shore Intermediate Maintenance Activities (SIMAs) and Naval Reserve Maintenance Facilities (SIMA NRMFs). At these commands Navy personnel with specialized facilities and training accomplish intermediate level repair work.

Intermediate level maintenance is that maintenance which is normally performed by Navy personnel stationed on tenders, repair ships, and at SIMAs and SIMA NRMFs. It normally consists of calibration; repair or replacement of damaged or unserviceable parts, components or assemblies; the emergency manufacture of unavailable parts; and providing technical assistance. [Ref. 5]

3. Depot Level

Depot level maintenance is that type of maintenance generally requiring a greater industrial capability than possessed by either organizational or intermediate level activities. It consists of that maintenance performed by shipyards, either private or

Navy, Naval Ship Repair Activities, or other shore based activities, on equipment requiring major overhaul or complete rebuild of parts, assemblies, subassemblies, end items, and complete platforms, including manufacture of parts.

The only work to be scheduled for accomplishment by depot level maintenance activities will be that which is not feasible to be accomplished by organizational or intermediate level maintenance activities because of insufficient time or manpower, or because it is beyond the capabilities of these fleet maintenance activities, or is of such a nature that split responsibility between Fleet and depot maintenance activities should be avoided. [Ref. 5]

B. INTERMEDIATE MAINTENANCE ACTIVITY MISSIONS

This thesis examines performance measures for the maintenance activities at the intermediate level. It is not concerned with organizational or depot level maintenance. A further explanation of the missions of Shore Intermediate Maintenance Activities, Repair Ships, and Tenders follows.

The mission of the Shore Intermediate Maintenance Activities (SIMAs) is to:

- Perform intermediate level maintenance for ships,
- Provide meaningful assignments ashore to support sea/shore rotation in order to retain the skilled Petty Officers needed to man the Fleet in peacetime and mobilization,
- Provide in rate training and experience for sea intensive enlisted personnel who repair and maintain shipboard systems,
- Provide a mobilization option for wartime maintenance and battle damage repair, and

- Provide billets co-located with Naval Reserve Force ships to support TAR personnel sea/shore rotation and retention. [Ref. 7]

Like Shore IMAs, the mission of Repair Ships and Tenders is to perform intermediate level maintenance for ships. However, their mission does not include the manpower rotation considerations and Naval Reserve support concerns listed above for Shore IMAs. Unlike Shore IMAs, Tenders and Repair Ships are not fixed in one location. They have the mobility necessary to provide intermediate level support, repair of battle damage and other emergent repairs to advance and forward areas when required. This unique feature, mobility, is also needed to redeploy intermediate maintenance capability between theaters in balance with the movement of operating forces. This reduces the investment needed for fixed overseas sites. [Ref. 7]

C. U. S. PACIFIC FLEET INTERMEDIATE MAINTENANCE ACTIVITIES

1. Description

There are eleven ship Intermediate Maintenance Activities (IMAs) assigned to the United States Pacific Fleet. Six are shore based facilities, four are Tenders, and one is a Repair Ship. They vary widely in size and capability. Table 1 lists the eleven IMAs and the number of personnel assigned to each.

All IMAs have the capability to do routine intermediate level work such as welding, valve work, pump repair, sheetmetal work, and electrical repair. The larger IMAs can provide such things as foundry work, diving services, lifeboat maintenance, electroplating, sonar repair, and gas turbine engine repair.

TABLE 1

U.S. PACIFIC FLEET
INTERMEDIATE MAINTENANCE ACTIVITIES

Name	Homeport	Personnel as of 3/92
SIMA San Diego	NA	2069
SIMA Long Beach	NA	789
SIMA Pearl Harbor	NA	625
SIMA San Francisco	NA	654
SIMA Naval Amphibious Base, Coronado, CA	NA	182
SIMA NRMF Puget Sound	NA	138
USS Acadia (AD 42)	San Diego	835*
USS Cape Cod (AD-43)	San Diego	863*
USS Samuel Gompers (AD-37)	Alameda, CA	792*
USS Prairie (AD-15)	Long Beach	364*
USS Jason (AR-8)	San Diego	437*

* IMA personnel only. Does not include other ship personnel.

2. Chain of Command

All Intermediate Maintenance Activities report to the Commander, Naval Surface Force Pacific (COMNAVSURFPAC) for the performance of their duties. The senior staff officer concerned is the Assistant Chief of Staff, Maintenance and Engineering, organizational code N4. Subordinate to N4 is the Force Intermediate

Maintenance Officer, code N41. A key assistant to N41 is the Intermediate Maintenance Plans and Programs Officer, code N411. The many duties of N411 include:

- Provide data for budget input and budget requirements and prepare budget recommendations for IMAs,
- Review Force IMA requirements and provide appropriate inputs to COMNAVSURFPAC long-term procurement requests,
- Participate as the COMNAVSURFPAC representative in development efforts in the ADP community which have a direct effect on the quality and/or improvement of Force maintenance,
- Direct the scheduling of IMA availabilities for Force units, and
- Research and monitor IMA utilization performance. [Ref. 8]

The Force Intermediate Maintenance Officer (N41) and the Assistant Chief of Staff, Maintenance and Engineering (N4) review and approve all reports from N411 before they are forwarded to higher authority.

This thesis addresses the final item on the list, the duty to "research and monitor IMA utilization performance". It does so by evaluating current methods used to monitor IMA performance and by recommending additional methods. Valid performance measures are necessary to support recommendations made about IMAs while carrying out the other N411 duties listed.

There is another level in the chain of command between COMNAVSURFPAC and the IMAs. The immediate senior for Intermediate Maintenance Activities (IMAs) is the local screening authority. The screening authority is discussed further in the subsection about work request flow.

D. INTERNAL INTERMEDIATE MAINTENANCE ACTIVITY ORGANIZATION

Intermediate Maintenance Activities are job shop facilities. They consist of several workcenters (or shops), each organized to do a particular type of work. Table 2 lists representative workcenters. Not all IMAs possess all workcenters. For example, SIMA San Francisco has 39 different workcenters while SIMA San Diego has 65. The alphanumeric names are standardized; for example, 35A will always refer to an optical workcenter regardless of where that workcenter is located. In addition to the production oriented workcenters, support workcenters exist as well. These include Planning and Estimating, Supply, Quality Assurance, and Automated Recordkeeping and Reports (ARRS).

E. WORK REQUEST FLOW

A request for intermediate level work can be initiated by a ship for several reasons. A piece of equipment may break in such a way that the ship's personnel cannot repair it. Routine tests may show that an item needs refurbishment available only at the intermediate level. A workspace may need new storage lockers. Mandatory periodic intermediate level tasks may be due. Regular wear and tear may require the replacement of various deck fittings, lengths of pipe, or portions of deckplate.

All requests are submitted via a standard work request document with formatted fields of data to enable computer systems to aid in the processing of the requests. Each ship maintains a list of its pending work requests, known as the Consolidated Ships

TABLE 2

PARTIAL LISTING OF INTERMEDIATE MAINTENANCE ACTIVITY WORKCENTERS

11A	shipfitter	51A	electrical
17A	sheetmetal	51F	gyro
26A	welding	56A	pipe
31A	inside machine	56C	flex hose
31D	valve repair	57A	lagging
31G	pump shop	64E	key and lock
31T	gas turbine	67A	electronics
35A	optical	67D	teletype

Maintenance Plan (CSMP). The list is maintained in a computer format.

All ships in a given geographic area routinely submit their worklists (CSMPs) to the local screening authority. The screening authority is a representative of COMNAVSURFPAC responsible for allocating work to the IMAs in that geographic area. For example, the screening authority in San Diego assigns work to SIMA San Diego, USS Acadia (AD-42), USS Cape Cod (AD-43), and USS Jason (AR-8). When deployed overseas, Tenders and Repair ships are under the authority of various deployed commanders.

The screening authority is a work request broker. It reviews all work requests in the geographic area for appropriateness and correctness and places the work with a maintenance facility that can complete the work. Much of the work is placed with Navy

Intermediate Maintenance Activities, although the screening authority also places work with civilian contractors.

Requests for work fall into two categories, planned and emergent. Planned work is accomplished during availabilities, marrying the customer ships with the repair activity, which can be an IMA or private sector contractor. An "availability " is a period of time when the ship is made available for work by the scheduling authority and when it receives priority service at the IMA. Availabilities are planned for weeks ahead of time to ensure materials are available and all jobs are planned. Current Pacific Fleet policy is that each ship should have at least one three-week availability each quarter. Mission degrading emergent work is accomplished at any time and is assigned to repair activities based on their capability, current workload, and operational necessity.

After a work request is accepted by the IMA, the job must be planned. Personnel from the IMA's Planning and Estimating workcenter review the job, visit the customer ship if necessary to gather additional information, order materials, and plan the number of manhours and skill types to get the job done. A lead workcenter is assigned and support workcenters are designated. Conducting centralized planning allows the planners to load the workcenters with the appropriate amount of work and to prepare realistic estimates of job completion dates. The work requests are completed by the IMA personnel, the job is accepted as complete and satisfactory by the customer ship, and the paperwork is completed to clear that work request from the ship's worklist (CSMP).

III. PERFORMANCE MEASURES

This chapter will define and discuss some terms and ideas critical to an understanding of performance measures. First, the idea of measurement itself will be examined. Second, various categories of performance measurement will be considered, including quantity, efficiency, effectiveness, and productivity.

A. MEASUREMENT

"Measure" is defined in the dictionary as "the act, process, or result of determining the dimensions, capacity, or amount of something" [Ref. 9]. Moore defines it as follows:

> "To *measure* a property means to assign numbers to units as a way of representing that property [Ref. 10]."

Useful measures require clear definitions of the property to be measured and the unit to be used to measure that property.

Some properties and units are widely accepted and understood. For example, it is difficult to find disagreement about what "length" is and difficult to find anyone who says "feet" or "meters" are inappropriate units to use to measure length. Unfortunately, there is not the same agreement about what to measure as an indicator of performance and what units to use for such measurement. Some common ground must be agreed upon before any meaningful discourse on performance can take place.

B. CATEGORIES OF PERFORMANCE MEASURES

Performance measures can be categorized in many ways. Considering it via the three categories of quantity, efficiency, and effectiveness is useful because the data examined later in the thesis in Chapters IV, V, and VI is grouped in that way. Attempts to measure productivity requires special comment because productivity can be defined using both an efficiency concept and an effectiveness concept.

1. Quantity

Quantity is the easiest category to discuss, but is not as easy to apply as it seems. Counting the number of items of interest is the straightforward way to find out how many of the items exist. If "number of items" is used as a comparison between groups, there is an underlying assumption that the items being counted are of the same quality. This is not necessarily a valid comparison. All football teams field eleven players, but no one would claim that, because they have the same number of players, the teams perform equally well. A real estate agent who sells twenty homes a month might appear to be a better agent than one who only sells one house every six months, but if the one house sold is a multi-million dollar mansion while the twenty others are small, low-priced homes, the agent who sells many fewer homes will still make more money. All home sales are not the same, just as all football players are not the same. The units used in the two examples are football players and homes. These units are not as clearly defined as feet or pounds and thus should only be used for comparisons with careful awareness of their shortcomings.

Measures of quantity are best used when the units are well defined, well understood, and well accepted by those using the measure.

2. Efficiency

Efficiency has been defined as "the ratio of service quantity output to the amount of input required to produce it [Ref. 11]." Calculation of an efficiency measure requires a measure of output and a measure of input. An output measure is the quantity of service units or product units that result from a task. An input measure is the quantity of a resource that has been applied to a task.

3. Effectiveness

Effectiveness has been defined as "the degree to which the intended public purposes of a service or activity are being met [Ref.11]". It is difficult to get a consensus on what "effectiveness" means because its definition is so context dependent. Effectiveness is often confused with words like efficiency, performance, and productivity by imprecise users. Webster's dictionary does not help matters by listing efficient and productive as synonyms for effective.

Before appropriate measures and units can be selected to measure effectiveness, the struggle over defining the purpose of a service or activity must be resolved. Businesses have a readily accepted measure of effectiveness. It's called profit. If a business doesn't make any money, it is definitely ineffective and will soon go out of business. Government services and non-profit organizations have a more difficult time measuring effectiveness because they do not produce goods or services that are

exchanged in the marketplace. They have no clearly defined and well-accepted measure of output like the monetary profit of a business.

The question of effectiveness is especially important in military problems because the military spends a lot of money doing a lot of tasks where performance is difficult to measure. How can the military demonstrate that it is spending money "effectively"? The desired output of the military is "readiness", the ability to respond in a timely manner to any threat to or assignment from the government. Defining military effectiveness and then somehow quantifying it will continue to be a challenge.

As used in operations research practice and in this thesis, effectiveness is not necessarily related to efficiency and productivity. A highly efficient organization may be ineffectual. For example, a firm that makes slide rules with a minimum number of workers and small amount of resources, demonstrating high efficiency, will not be very effective at meeting the calculating needs of today's high school students. They all want electronic calculators. Likewise, a greatly effective organization may be inefficient, possessing substantial room for efficiency improvement. A charitable organization might regularly feed the homeless in its community, but if it's paying a world class chef high wages to do something volunteers might do equally as well for no pay, it could improve its efficiency.

4. Productivity

Levitan and Werneke write,

> For analysts of economic performance, productivity denotes the efficiency with which resources--people, tools, knowledge, and energy--are used to produce goods and services for the marketplace. [Ref. 12]

Once units for output and input are selected, productivity can be defined as the ratio of output units to input units. Usually the units of output measure how much of a good or service is produced. The idea is that if the same amount of output is made with less input, productivity is higher. The interpretation of this definition of productivity is limited as described by Levitan and Werneke:

> An efficiency concept of productivity, however, is narrower than the idea of product quality, for economic efficiency is concerned only with the output of goods and services and not with how well the products meet consumers' needs or wants...Productivity, then, is a concept of production rather than a measurement of consumption or social welfare. [Ref. 12]

They point out that an efficiency concept of productivity is primarily concerned with quantity of output. No consideration is given as to whether or not that output is desired by the customer or is the best use of the resources required to produce it. An effectiveness concept of productivity can be used to incorporate product quality and customer satisfaction in the measurement. Rather than using an output measure of quantity in the productivity ratio, the output measure used is a measure of effectiveness. The effectiveness concept of productivity is not often used because it is difficult to define effectiveness measures.

C. SUMMARY

People concerned with money and budgets are often drawn to measures of efficiency and productivity. However, the customer is concerned with effectiveness. Is the organization doing what it is supposed to be doing? Is the mission being accomplished? To what extent is the mission being accomplished? Results are what

matters. The proper time to address efficiency and productivity is after effectiveness has been determined. Only after it has been determined that an organization is accomplishing its intended mission is it worthwhile to work on improving efficiency and productivity.

IV. THE MAINTENANCE RESOURCE MANAGEMENT SYSTEM

This chapter will describe the Maintenance Resource Management System (MRMS) and discuss the measures of performance calculated by MRMS. It will comment on the usefulness of MRMS as an internal management tool. It will describe some dangers that are present when MRMS data is used to make comparisons between Intermediate Maintenance Activities (IMAs). Finally, historical MRMS data will be analyzed to determine what the data show about IMA performance.

A. BACKGROUND

The Maintenance Resource Management System (MRMS) is an automated work management system used by Navy ship Intermediate Maintenance Activities (IMAs). It is intended "to provide an information support capability to enhance maintenance management within the IMA community in order to ensure the material readiness of the Pacific and Atlantic Fleets" [Ref. 13].

MRMS was selected in 1988 as the common information management system for all Navy ship Intermediate Maintenance Activities. MRMS is in use at all Pacific Fleet shore IMAs and at two afloat IMAs. MRMS will be installed aboard the remaining afloat IMAs by the end of 1993.

MRMS is the most recent product in a series of systems that were specifically designed to measure productivity. The initial impetus for the development of a

maintenance management system was the Department of Defense's increased emphasis on productivity in the mid nineteen-seventies. The Navy started development of productivity measurement systems after various Government Accounting Office reports criticized the absence of any way to quantify productivity at Navy maintenance facilities.

The Maintenance Resource Management System (MRMS) provides extensive maintenance management capability within a geographic area. It supports the area maintenance manager and the individual Intermediate Maintenance Activities ashore and afloat within that geographic area. To accomplish this, MRMS has been designed with two major components, the Type Commander's Representative (TYCOM Rep) Component and the Intermediate Maintenance Activity (IMA) Component.

The TYCOM Rep Component provides the area maintenance manager, also known as the screening authority, with the capability on-line to store, screen, assign and track intermediate level work that has been requested for accomplishment within his geographic area. The IMA Component provides the capability on-line to receive, induct, plan, order material for, schedule, issue and monitor the progress toward completion of the assigned intermediate level work.[Ref. 14]

The performance measures examined in this chapter are calculated by the IMA Component of the Maintenance Resource Management System.

The centerpiece of the MRMS IMA Component is a standards-based automated work planning system which develops output measures for work accomplishment. Using various work measurement techniques, a database of standard times for work tasks has been developed. The database is used by IMA planners to "build up" jobs from

individual work tasks. After adding time for such things as travel, job set-up, and worker skill level, each job is assigned a "planned manhour" value. The planned manhours can be thought of as the potential "worth" or output value of the job. As the job is completed the planned manhours are converted directly to "earned manhours", the unit used to measure output in MRMS. An earned manhour is thus a planned manhour that has been completed. Earned manhours are the only measure of output used to calculate performance measures in the Maintenance Resource Management System. Earned manhours are not the same thing as actual manhours expended on a job. The actual manhours can be greater or less than the earned manhours. Earned manhours can never exceed the number of planned manhours. Only in an ideal situation with perfect planning and perfect execution and no variation will earned manhours and actual expended manhours be equal.

The developers of MRMS state that the system allows maintenance managers to:

- Capture, address and dispose of more customer maintenance items than heretofore,
- Provide efficient area work brokering,
- Improve IMA shop loading,
- Reduce IMA shop throughput time,
- Promote higher quality output and reduce paperwork, and
- Accurately measure IMA output and input, hence performance and productivity. [Ref. 15]

This thesis primarily addresses the final item on the list, that is, performance and productivity measurement.

The fact that MRMS does not measure IMA *effectiveness* but rather IMA *productivity* was clearly understood by the developers of the system. Biher and Eldred write,

> For many years the productive efficiency of these activities was not of great concern to the Navy. The sailor workforce was a "free good" and the overriding goal of ship readiness excused excesses. The IMAs were measured as to their effectiveness. Did they get the job done and done quickly? Quality of work and economy of resources were not measured. [Ref. 16]

They clearly distinguish between measuring "quality of work and economy of resources", which MRMS is designed to do, and measuring effectiveness, defined by them as timely response, for which MRMS is *not* designed.

The Maintenance Resource Management System was designed using industrial engineering ideas and therefore uses industrial engineering terms. Proper understanding of the definitions used in the system is critical. Interpreting the MRMS measurements using "everyday" definitions of the words used can give misleading results.

The next section will define and describe six MRMS measures: performance, utilization, productivity, workload performance, load ratio, and production support ratio.

B. MEASURES OF PERFORMANCE USED

The following definitions are from the MRMS Methodology and Procedures Manual.[Ref. 17] The first section defines the quantities used to calculate the

MRMS performance measures. The second section defines the formulas used to calculate the measures.

1. Definition of Terms

EARNED MAN-HOURS The total number of planned man-hours assigned to that work which was completed by Repair Department production shops during the reported period.

TOTAL MAN-HOURS ASSIGNED The total number of man-hours assigned to the Repair Department production shops for the reported period.

GROSS PRODUCTIVE AVAILABLE MAN-HOURS The total number of man-hours assigned less the total number of productive support man-hours assigned for the reported period.

GROSS PRODUCTIVE SUPPORT MAN-HOURS The total number of productive support man-hours assigned for the reporting period.

NET PRODUCTIVE AVAILABLE MAN-HOURS The total number of productive man-hours available to production supervisors, equal to GROSS PRODUCTIVE AVAILABLE MAN-HOURS minus allowed deductions.

NET PRODUCTIVE SUPPORT MAN-HOURS The total number of productive support man-hours available for the reporting period.

MAN-HOURS UNASSIGNED TO JCNS The total man-hours of time when technicians, otherwise available for work, are not so assigned because of lack of JCNs (job control numbers, i.e., work requests) to be worked.

The following relationships between terms are true.

TOTAL MHRS ASSIGNED = GROSS PRODUCTIVE AVAILABLE MHRS + GROSS PRODUCTIVE SUPPORT MHRS.

NET PRODUCTIVE AVAILABLE MHRS = EARNED MHRS + MHRS UNASSIGNED TO JCNs + explained work delays + difference between mhrs expended on jobs and mhrs planned for jobs.

Note that the last term on the right hand side of the above equation can be positive or negative. The details of the last two terms in the final equation are not presented in this thesis because they are beyond its scope. Complete information is available in the Maintenance Resource Management System Users Manual, Reference 13.

2. Definition of Measures

The six measures calculated by MRMS are

$$PERFORMANCE = \frac{EARNED\ MANHOURS}{NET\ PRODUCTIVE\ AVAILABLE\ MANHOURS},$$

$$UTILIZATION = \frac{NET\ PRODUCTIVE\ AVAILABLE\ MANHOURS}{GROSS\ PRODUCTIVE\ AVAILABLE\ MANHOURS},$$

$$PRODUCTIVITY = \frac{EARNED\ MANHOURS}{GROSS\ PRODUCTIVE\ AVAILABLE\ MANHOURS},$$

$$LOAD\ RATIO = \frac{NET\ PROD\ AVAIL\ MHRS - MHRS\ UNASSIGNED\ TO\ JCN}{NET\ PRODUCTIVE\ AVAILABLE\ MANHOURS},$$

$$\begin{array}{l} WORKLOAD \\ PERFORMANCE \end{array} = \frac{EARNED\ MANHOURS}{NET\ PROD\ MHRS\ AVAIL - MHRS\ UNASSIGNED\ TO\ JCN},$$

$$\begin{array}{l} PRODUCTIVE \\ SUPPORT\ RATIO \end{array} = \frac{GROSS\ PRODUCTIVE\ SUPPORT\ AVAILABLE\ MHRS}{GROSS\ AVAILABLE\ MANHOURS}.$$

Note that PRODUCTIVITY and WORKLOAD PERFORMANCE can be calculated directly from the other terms. That is,

$$PRODUCTIVITY = PERFORMANCE \times UTILIZATION\text{ , and}$$

$$WORKLOAD\ PERFORMANCE = \frac{PERFORMANCE}{LOAD\ RATIO}.$$

C. ANALYSIS OF MRMS MEASURES OF PERFORMANCE

The training materials and user's manuals provided by the MRMS developers go into great detail about how to use the system to evaluate IMA workcenter performance

and improve the management of work. MRMS has the potential to be an excellent tool for the IMA manager to monitor and improve performance inside his own IMA. However, MRMS data is not well suited for comparisons between different IMAs.

If MRMS data is used to compare Intermediate Maintenance Activities the following facts must be considered in order to avoid erroneous conclusions.

- No common guidance for system use is established.
- No performance goals are established.
- Aggregation of entire IMA masks overloads and underloads in individual shops.
- The system measures are percentages, not absolute measures.
- There is no link to impact on fleet readiness.
- Quality of work and customer satisfaction are not considered.
- The terms used in MRMS are easily misunderstood by an observer unfamiliar with the system.
- The Intermediate Maintenance Activities differ significantly and operate in different circumstances, serving varied customer bases with different impediments to good performance.

D. ANALYSIS OF HISTORICAL DATA

The concerns expressed in the preceding section explain why it can be dangerous to use Maintenance Resource Management System (MRMS) data to compare Intermediate Maintenance Activity (IMA) performance. However, there is information to be gained from a cautious examination of the data. The following analysis applies some statistical

techniques to demonstrate that there are statistical reasons for not using MRMS as a comparison method as well as qualitative reasons.

1. Data Description

The data analyzed in this section is taken from twenty-seven months of Maintenance Resource Management System monthly reports from four Shore Intermediate Maintenance Activities (SIMAs). The four SIMAs are SIMA Long Beach, SIMA Pearl Harbor, SIMA San Diego, and SIMA San Francisco. The months considered are January 1990 through March 1992. MRMS data from Tenders and Repair Ships was available for only one ship because not all ships have been equipped with MRMS. Because the afloat IMAs are so different from the shore IMAs, the data from the one ship was not included in the analysis.

Table 3 shows some of the descriptive statistics for the six MRMS measures for each of the four shore IMAs analyzed. The means and standard deviations were calculated using the 27 observations of monthly measures. The original numerator and denominator values were not used because they were not available. Because the monthly measures are ratios, this approach can lead to errors under some circumstances. For example, consider UTILIZATION. Suppose three months data is as follows:

month	Gross Prod. Avail. MHRS	Net Prod. Avail. MHRS	UTILIZATION
1	1000	250	0.25
2	100	50	0.50
3	100	75	0.75 .

The actual average UTILIZATION for the three months, calculated using the sum of the numerators divided by the sum of the denominators, is 375/1200 = 0.31. The mean

TABLE 3

SUMMARY OF MRMS PERFORMANCE MEASURES EXPRESSED AS PERCENTAGES

		mean	std dev	median	min	max
PERFORMANCE	Long Beach	75.5	6.2	76	63	88
	Pearl Harbor	91.4	6.4	90	78	107
	San Diego	60.5	4.5	61	46	66
	San Francisco	76.4	7.8	77	54	91
UTILIZATION	Long Beach	60.6	2.5	61	53	64
	Pearl Harbor	58.9	6.7	57	48	73
	San Diego	70.5	5.4	71	58	81
	San Francisco	59.4	6.7	59	46	72
PRODUCTIVITY	Long Beach	45.7	4.8	46	33	56
	Pearl Harbor	54.1	8.6	52	41	72
	San Diego	42.7	5.3	43	31	51
	San Francisco	45.8	8.6	45	28	66
LOAD RATIO	Long Beach	93.5	2.0	94	90	97
	Pearl Harbor	96.9	2.7	97	89	100
	San Diego	96.9	1.4	97	95	99
	San Francisco	85.0	4.6	84	76	94
WORKLOAD PERFORMANCE	Long Beach	80.6	6.9	82	69	91
	Pearl Harbor	94.4	5.5	94	83	111
	San Diego	62.3	4.3	63	48	68
	San Francisco	90.0	7.4	91	62	97
PRODUCTIVE SUPPORT RATIO	Long Beach	34.7	2.0	35	30	39
	Pearl Harbor	38.3	2.4	39	31	43
	San Diego	42.4	1.6	42	40	45
	San Francisco	41.0	1.8	40	39	45

UTILIZATION using the three monthly UTILIZATION values is $(0.25+0.50+0.75)/3 = 0.50$. With consideration given to this potential error, the second method was used to calculate the means and standard deviations in Table 3. As long as the denominator values in the measures remain fairly constant, the error from using the monthly measures instead of the original numerator and denominator values is small.

2. Comparisons Between Intermediate Maintenance Activities

Before any comparisons between the IMAs were made, the samples were tested for randomness using the Runs Test [Ref. 18]. All samples failed the test, indicating that the monthly measures cannot be tested using methods that require an assumption of randomly selected observations. This is assumed to occur due to the time-series nature of the data. Nonparametric statistical tests were therefore selected.

The Friedman Test with Blocking was chosen to compare the samples.[Ref. 6] To compare the four IMAs, months were the blocks and each IMA was considered a treatment. Because the test ranks observations only within each month and not between months, correlation from month to month should not affect the validity of the test results.

The hypotheses for the Friedman Test are

$$H_0 : \theta_1 = \ldots = \theta_k, \textit{ and}$$

$$H_A : \textit{Not all } \theta_i \textit{ are equal,}$$

where Θ_i is the median of sample i.

The Friedman test statistic is defined as

$$T = \left[\frac{12}{bk(k+1)} \sum_{j=1}^{k} R_j^2\right] - 3b(k+1), \textit{ where}$$

b is the number of blocks,

k is the number of treatments, and

R_j is the sum of the ranks assigned to treatment j.

Table 4 contains the test results when all four IMAs are compared.

The decision rule for the Friedman Test is to reject the null hypothesis at the level α if the test statistic **T** exceeds the 1-α quantile of a chi-square random variable with k-1 degrees of freedom.

TABLE 4

RESULTS OF FRIEDMAN TEST FOR COMPARING IMAs FOUR AT A TIME

Measure	Test Statistic T	Decision
PERFORMANCE	65.39	reject H_0
UTILIZATION	49.46	reject H_0
PRODUCTIVITY	26.84	reject H_0
LOAD RATIO	62.94	reject H_0
WORKLOAD PERFORMANCE	67.50	reject H_0
PRODUCTIVE SUPPORT RATIO	66.50	reject H_0

Decision rule: For $\alpha = 0.05$, reject H_0 when $T > 7.815$.

All of the tests reject the null hypothesis that all four sample medians are the same. That is, there are statistically significant differences between the four IMAs for all six performance measures. Further comparisons between the IMAs, three at a time and two at a time, give the results shown in Tables 5 and 6. In several categories, it is not possible to say with confidence that there are differences in the measures at the four IMAs. Table 7 summarizes the findings.

It would appear that Pearl Harbor was the "best" IMA of the four because it has the highest numbers in two of the six measures, and tied for best with San Diego

and San Francisco in two others. However, if UTILIZATION was deemed to be the most significant measure, San Diego would be the "best" IMA even though it has the lowest scores in several other measures.

All conclusions about relative performance are suspect without a common directive for implementation of the Maintenance Resource Management System. Currently, each Intermediate Maintenance Activity decides how it will count production support personnel and direct production personnel. They also decide independently about applying allowed deductions. For example, some IMAs consider the productive workday to be eight hours long, while others allow a thirty minute administrative deduction for

TABLE 5

RESULTS OF FRIEDMAN TEST FOR COMPARING IMAs THREE AT A TIME

	LB=1, PH=2, SD=3, SF=4			
	1,2,3	1,2,4	1,3,4	2,3,4
PERFORMANCE	50.30	30.91	37.85	49.13
UTILIZATION	41.06	3.13	39.57	40.57
PRODUCTIVITY	19.91	16.08	2.46	29.17
LOAD RATIO	23.91	47.91	48.67	41.17
WORKLOAD PERFORMANCE	53.02	31.50	47.19	42.35
PRODUCTIVE SUPPORT RATIO	48.22	45.39	43.17	34.06

Decision rule: For $\alpha = 0.05$, reject H_0 when $T > 5.99$.

TABLE 6

RESULTS OF FRIEDMAN TEST FOR COMPARING IMAs TWO AT A TIME

	PERFORMANCE	LOAD RATIO	WORKLOAD PERFORMANCE	PRODUCTIVE SUPPORT RATIO
LB/PH	19.59	14.81	25.04	19.59
LB/SD	27	16.33	27	27
LB/SF	0.33	27	13.37	27
PH/SD	27	1.33	27	23.15
PH/SF	21.33	27	3.71	17.93
SD/SF	23.15	27	27	5.33

Reject H_0 at $\alpha = 0.05$ when $T > 3.841$.

morning muster and afternoon cleanup, giving a seven-and-a-half hour workday. Over a period of months and hundreds of workers, that thirty minute difference may show performance differences that are not real, but rather a result of the definition of MRMS measures policies. The MRMS measures may indeed indicate performance differences, but the users of MRMS might be measuring different things.

E. SUMMARY

Maintenance Resource Management System performance data should be used internally by each Intermediate Maintenance Activity as a management tool to monitor and improve efficiency. After all, the system was designed to do just that.

Officials at Commander, Naval Surface Force, Pacific (COMNAVSURFPAC) must provide standard guidance to the IMAs for use of MRMS before they can use MRMS

TABLE 7

SUMMARY OF COMPARISONS
BETWEEN IMAs

	Long Beach	Pearl Harbor	San Diego	San Francisco
PERFORMANCE	same	1	4	same
UTILIZATION	same	same	1	same
PRODUCTIVITY	same	1	same	same
LOAD RATIO	3	same	same	4
WORKLOAD PERFORMANCE	3	same	4	same
PRODUCTIVE SUPPORT RATIO	1	2	4	3

performance data to compare IMAs. An instruction defining exactly how to categorize manhours, stating explicitly how to account for authorized deductions, and providing some reasonable performance goal would be helpful. In addition, they must be careful to understand what the data does and does not represent. MRMS data measures efficiency, not effectiveness. COMNAVSURFPAC officials must use other categories of measures together with the MRMS measurement data to get a complete picture of IMA performance.

V. MONTHLY IMA UTILIZATION REPORT

This chapter describes the Monthly IMA Utilization Report, discusses its use, and examines Fiscal Year 1991 data from the report.

A. DESCRIPTION

The Monthly IMA Utilization Report is a report of *quantities*. There is nothing in the data, as reported, that purports to measure *efficiency* or *effectiveness*.

The report is required by Commander, Naval Surface Force, U.S. Pacific Fleet (COMNAVSURFPAC).[Ref. 19] The data collected in the report are divided into several sections, some of which are Manning Allocation, IMA Manning Utilization, Man Hour Utilization, and Work Request Submission.

The instruction establishing the report states,

> The efficient and effective utilization of maintenance resources is a high priority matter for the Navy. Data on utilization is an important input for monitoring IMA performance, TYCOM decisions on maintenance, meeting CINCPACFLT and CNO reporting requirements and developing budgetary justification for manpower and funding. [Ref. 19]

Although the instruction includes the words "efficient" and "effective", it does not define what is meant by the words in the context of IMA performance. It also does not explain how the data collected in the report can be used to measure efficiency and effectiveness.

Note that the term "utilization" is used here to mean "usage" or "employment". It is not the same definition of "utilization" used in the Maintenance Resource Management System (MRMS) as described in Chapter IV. This dual usage of the same word, but with different meanings, is a source of much confusion to people using both the MRMS report and the Monthly IMA Utilization Report.

B. DISCUSSION

The numbers collected in the Monthly IMA Utilization Report answer questions of the form "How much?" How many manhours were expended on customers this month? How many work requests were completed? How many work requests were rejected? How many people were assigned to the Intermediate Maintenance Activity? There is an implied understanding that more is better in measures of quantity. This is not necessarily true. Doing more jobs or expending more manhours on customers is not really a goal of an Intermediate Maintenance Activity.

The assumption that more is obviously better is a common mistake when defining and using measures of effectiveness. A classic example is that of analysts studying Allied antisubmarine warfare efforts against German U-boats during World War II. Originally, the analysts proposed "number of U-boats sunk" as a measure of antisubmarine warfare effectiveness. This definition assumes that the goal of antisubmarine warfare was to sink U-boats. However, the real goal was to get cargo across the ocean without having it sunk by enemy attack. Thus, an appropriate measure of antisubmarine warfare effectiveness was merchant ships protected from sinking or tons

of cargo delivered, not number of U-boats sunk. The number of U-boats sunk might actually go down while cargo delivered goes up due to better antisubmarine protection for cargo ship convoys and less emphasis on submarine sinking. [Ref. 20]

In a like manner, measuring the amount of work done by an Intermediate Maintenance Activity may not be measuring how well the IMA is achieving its performance goal. In theory the IMAs could work 24 hours a day making plaques and sheetmetal cabinets, while pumps and motors and radars and sonars lay broken. The IMA certainly did a lot of work, but what did it accomplish? What did it contribute to Fleet readiness? The IMA may fix the pumps and motors and radars and sonars, only to have them break again due to poor quality work. The IMA will expend more manhours and complete more jobs because of excessive rework. Is this what is meant by a "good" or "efficient" or "effective" IMA? Probably not.

The real goal of an IMA is to do, in a timely manner, all the intermediate level work *that needs to be done*. It may be true that the reason a particular IMA is doing less work than another is because there is less work to be done. Perhaps all the customer ships in their area have excellent maintenance and nothing ever breaks. If all the work *that needs to be done* is complete, it's foolish to "make work" just to drive up reported quantities.

Likewise, an IMA may be working overtime, expending massive amounts of manhours on customers and completing thousands of jobs, but only half of the work *that needs to be done* is being accomplished.

The measures of quantity of work reported in the Monthly IMA Utilization Report do not address any aspect of how much work *needs to be done*.

Thus, the validity and meaningfulness of the quantities reported depends on the integrity of the IMA management, screening authority, and customer ships. It must be assumed that all work that needs to be done is attempted and that only work that needs to be done and should be done by an IMA is attempted. Cheating, once it is clear that number of jobs or number of manhours expended is the "important" number, is a temptation for IMAs more determined to look good than to actually be good. Because of this, both quantities are looked at with a jaundiced eye. "Gut feeling" and "waterfront reputation" carry more weight as an evaluation of IMA performance than the numbers in the Monthly IMA Utilization Report.

In spite of the distrust with which the numbers are viewed, they are collected and have the potential to provide useful information about IMA performance. The next section examines data reported in Fiscal Year 1991.

C. DATA

The data examined in this section is from the Monthly IMA Utilization Reports submitted in Fiscal Year 1991 by all eleven U.S. Pacific Fleet Intermediate Maintenance Activities (IMAs). Table 8 contains the legend used to identify the IMAs in all graphs and tables of performance data.

First the data as reported will be examined. Second some derived (calculated) terms are examined.

1. Data as Reported

The two leading ways to quantify the amount of work done by an Intermediate Maintenance Activity are customer manhours expended and number of work requests completed. Quantities for Fiscal Year 1991 are shown in Figures 1 and 2. Both of these measures mask aspects of what was actually accomplished by the IMA. Counting manhours doesn't indicate how well the workers performed. Did they do the work in a "reasonable" amount of time or did they use "too much" time? What type of work was done? What type of work was left undone? There is a potential to overlook the fact that some IMAs have more personnel than others. It seems obvious that an IMA with more workers would expend more manhours on customers.

TABLE 8

LEGEND USED IN GRAPHS AND TABLES

AC	USS Acadia (AD-42)	PS	Puget Sound
CC	USS Cape Cod (AD-43)	NAB	NAB Coronado
GOM	USS Samuel Gompers (AD-37)	LB	SIMA Long Beach
JA	USS Jason (AR-8)	PH	SIMA Pearl Harbor
PR	USS Prairie (AD-15)	SD	SIMA San Diego
		SF	SIMA San Francisco

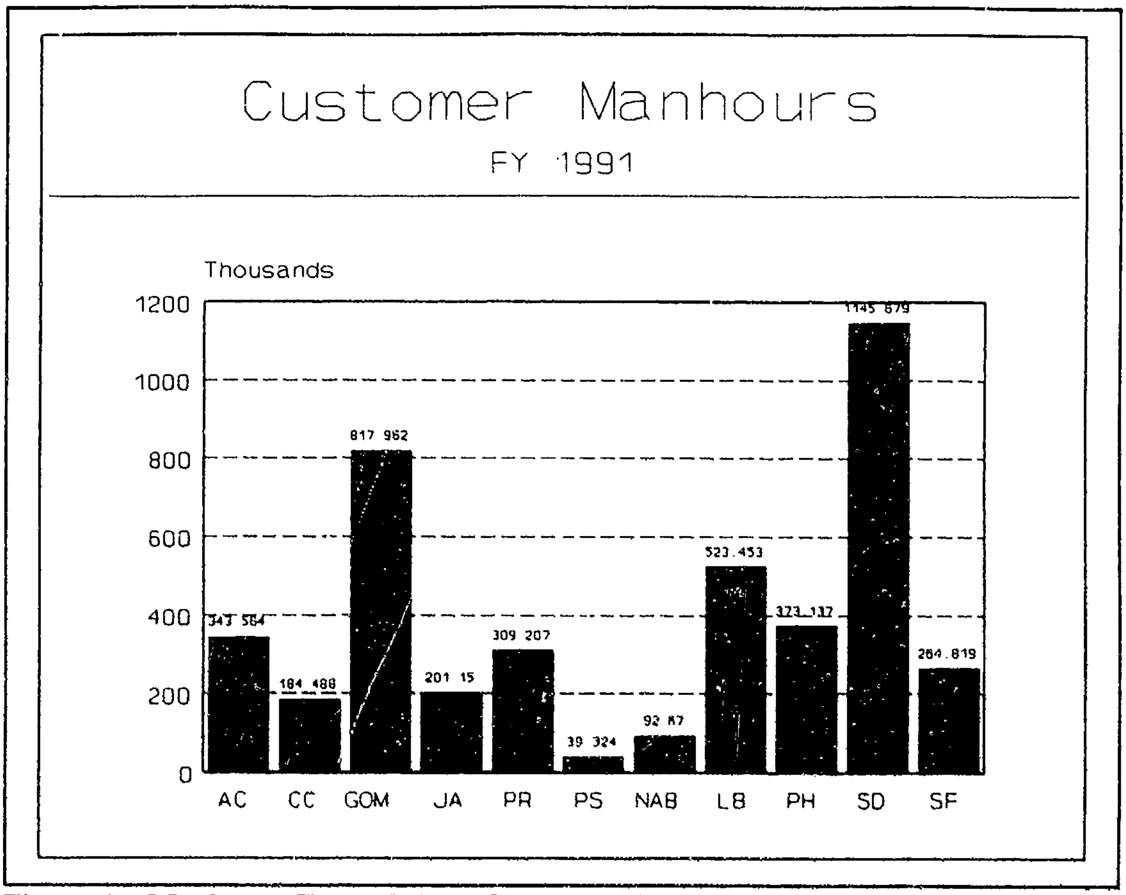

Figure 1. Manhours Expended on Customers in FY 1991 by IMAs.

The problem with counting work requests is that the work requests are so dissimilar. Unlike identical items manufactured on an assembly line, intermediate ship maintenance tasks are extremely diverse. A work request could require one locksmith to expend two hours drilling open a locked file cabinet or it could require several electricians and welders to work many days installing waterline security lights. A job repairing a main feed pump on a Sunday afternoon might allow a ship to meet a critical operational commitment on Monday morning, while a job to manufacture decorative brow skirts could require hours and hours of labor, but have no discernible impact on readiness. The difficulty and significance of work requests can differ greatly. In spite

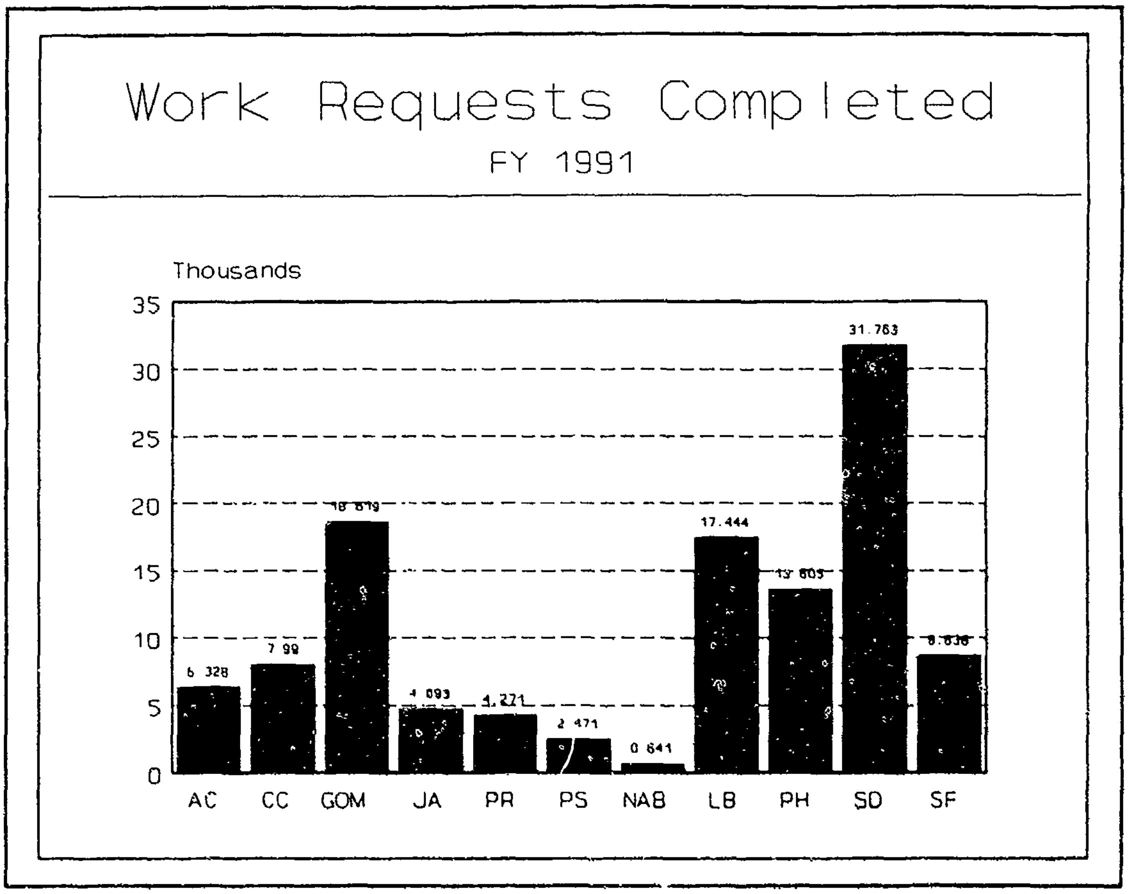

Figure 2. Number of work requests completed in FY 1991 by IMAs.

of this, each work request described above would still count as one item, even though it could be argued that their worth is not equal.

Absolute quantities give no information about efficiency or effectiveness. All that can be concluded is that one IMA expended more manhours or completed more work requests than another. Further examination of various derived values may be better suited to answer questions of efficiency and effectiveness.

2. Derived (Calculated) Values

There isn't anything in the Monthly IMA Utilization Report that can reasonably be used to measure efficiency. However, various numbers can be calculated

to describe IMA performance and that performance can be deemed more or less effective. It all depends on how "effective" is defined.

a. Percent of Work Requests Accepted

If an effective IMA is defined as one that accepts as many work requests as are presented to it, then "percent of work requests accepted" is an appropriate measure of effectiveness (MOE). A higher value would indicate a more effective IMA. Table 9 lists the percent of work requests accepted by the IMAs in Fiscal Year 1991.

TABLE 9

WORK REQUEST ACCEPTANCE RATE

IMA	# wr accept	# wr reject	% accept	% reject
AC	7995	73	99	1
CC	8102	420	95	5
GOM	18487	0	100	0
JA	6157	0	100	0
PR	4695	45	99	1
PS	2991	339	90	10
NAB	823	91	90	10
LB	19545	269	99	1
PH	14872	630	96	4
SD	38719	2522	94	6
SF	11016	983	92	8

Work requests can be rejected for good reasons which may not be caused by a performance deficiency by the IMA. For example, a work request may be submitted that is beyond the capability of a particular IMA. The customer ships may be filling out the work requests improperly, providing inaccurate or insufficient information making it impossible for the IMA to accept the work. A piece of equipment may no longer be supported by its manufacturer, making repair parts unavailable. Thus, some percentage of work request rejection is acceptable. Indeed, the 10% rejection rate at SIMA Puget Sound and NAB Coronado may be caused in part by capability shortcomings of their extremely limited facilities. Big changes in the MOE at an IMA or an IMA whose MOE differs greatly from that of the other IMAs should motivate further investigation as to why that occurred. Again, the importance of using measurement data as a way to improve performance is emphasized. The *reasons* for changes in the MOEs must be sought out and either praised or corrected, else the effort expended in measurement is wasted.

b. When Work Requests are Accepted

COMNAVSURFPAC divides work requests accepted into three groups based on when they are accepted: advance, supplemental, and late or emergent. For Tenders and Repair ships advance is defined as 35 days prior to availability start date. For Shore IMAs, advance is defined as 45 days prior to availability start date. Supplemental work requests are those accepted between the advance date and the availability start date. Late or emergent work requests are work requests received after

the availability start date and all work requests received that are not associated with an availability.

Table 10 shows the distribution of work requests accepted by the IMAs into the three categories. Interpreting the breakdown as an indication of IMA effectiveness can lead to completely opposite findings. Consider the percentage of late work requests accepted. A high value here could indicate a good performance trait or a bad performance trait. The good performance trait indicated is a willingness to accept emergent work and/or aggressive identification of work on the customer ships even after the availability start date. The bad performance trait indicated is slow response to work requests submitted, delaying the work acceptance decision, and/or a failure on the part of the customer ship to plan ahead and identify work in advance.

A high number of late work requests might result due to short notice availabilities, scheduled with little lead time. Such availabilities are common for deployed Tenders and Repair Ships.

The analysis of when work requests were accepted does describe an aspect of IMA performance. but additional information as to why the particular distribution occurred is necessary before a given distribution can be characterized as indicating "good" or "bad" performance.

c. ***Manhours per Work Request***

The two quantities of output measured, customer manhours and number of work requests, can be combined to calculate manhours per work request. If all IMAs

TABLE 10

ACCEPTANCE TIMING OF WORK REQUESTS ACCEPTED FY 1991

IMA	# wr accepted	% advance	% supplemental	% late
AC	7995	44	18	38
CC	8102	13	20	67
GOM	18487	1	47	52
JA	6157	22	13	65
PR	4695	25	5	70
PS	2991	9	29	62
NAB	823	77	8	15
LB	19545	58	10	32
PH	14872	22	30	48
SD	38719	49	13	38
SF	11016	36	2	62

are doing approximately the same mix of simple and difficult tasks, the number should be about the same for all IMAs. Table 11 lists manhours per work request for the IMAs. USS Prairie (AD-15) at 172.4 and USS Cape Cod (AD-43) at 23.1 stand out as different among the tenders, and NAB Coronado at 144.6 and SIMA Puget Sound at 15.9 stand out as different among the shore facilities. The numbers indicate that the work requests completed by USS Prairie and NAB Coronado required more manhours, on average, than those completed by SIMA Puget Sound and NAB Coronado. Higher manhours per work

request could indicate more complex jobs requiring more time or people to complete, easy jobs that are just large, or overstaffing on jobs. Lower manhours per work request could indicate more efficient workmanship, or an unwillingness to accept difficult jobs that need many manhours to complete. The determination as to whether or not the significantly different values for manhours per work request indicate a good performance trait or a bad performance trait can only be made after further investigation.

TABLE 11

DERIVED MEASURES USING MANHOURS
FY 1991

IMA	mhrs/work request	mhrs/ima person/month	mhrs/ repair labor person/month
AC	54.3	40.9	81.9
CC	23.1	23.3	42.4
GOM	43.9	98.3	195.5
JA	42.9	48.7	119.9
PR	72.4	71.4	59.1
PS	15.9	24.3	139.5
NAB	144.6	53.1	93.5
LB	30.0	58.7	96.2
PH	27.4	51.3	84.7
SD	36.1	52.8	97.5
SF	30.7	41.4	76.4

Table 11 also contains values for customer manhours per person assigned to the IMA per month and customer manhours per person assigned to repair labor per month. The first includes all IMA personnel, including both repair labor and repair support. The second uses only personnel assigned to direct repair production work. Again, a few observations stand out as noticeably different from the others. USS Cape Cod (AD-43) has the smallest numbers of customer manhours expended per person per month in both columns, 23.3 and 42.4. USS Samuel Gompers (AD-37) has the largest numbers, 98.3 and 195.5. The USS Samuel Gompers numbers are more than four times the numbers reported by USS Cape Cod. This large difference indicates that the two ships are probably defining their units of measurement differently.

d. Relation Between Number of Personnel and Amount of Work Done

It seems reasonable to examine the relationship between the amount of repair labor available to do work and the number of customer manhours expended. More workers should lead to more work completed. Figure 4 shows a scatter plot of customer manhours expended per year versus repair labor man-months per year. Superimposed on the plot is a line fitted using a least squares fit. The commercial software MINITAB was used to do the least squares fit.

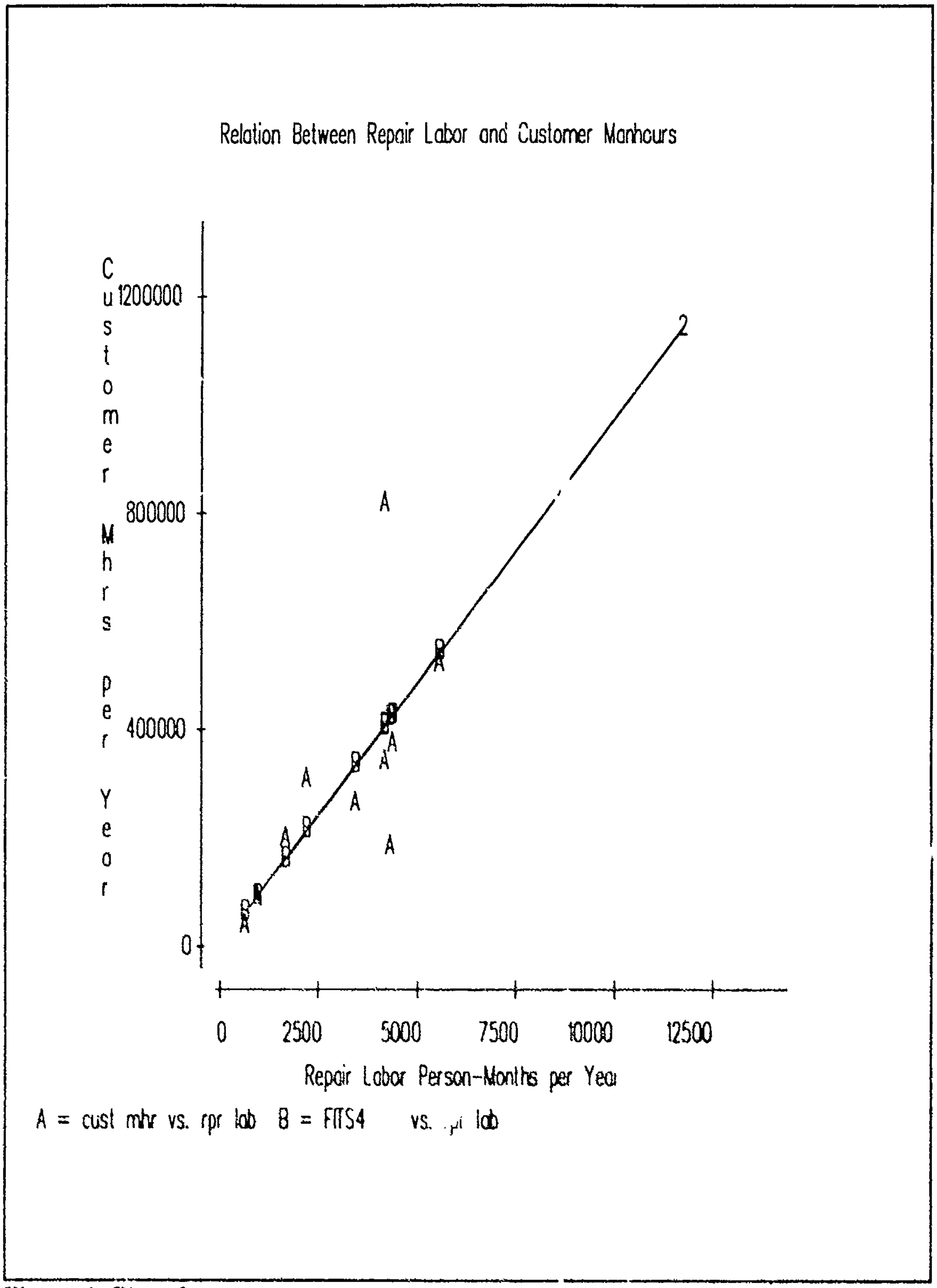

Figure 3. Plot of customer manhours expended vs. repair labor man-months. Each point represents one IMA.

The eleven data points, one for each IMA, indicate a strong linear relationship between direct production repair labor man-months and customer manhours expended. The p-value of the fit is 0.000. The fitted equation is

customer manhours expended per year =

97.59 x repair man-months per year.

This means that on average, each person assigned to direct production repair labor, not production support labor, expends 97.59 labor hours per month on customers. Obviously some individuals will work more than others due to the different types of work done in the various shops. However, the fitted equation does immediately present the question of what was done during all the other available workhours of the month. Assuming a work month of twenty 7.5-hour days leaves over fifty hours per month per worker that are not charged to customer jobs. Perhaps that time is required to fulfill training, internal maintenance, and other administrative needs. Perhaps the time is available for additional work. Additional study is necessary to determine if the 97.59 labor hours per month per worker is the appropriate performance level for the IMAs.

There are two observations on the plot that are noticeable as having large residuals. The one below the line represents USS Cape Cod (AD-43) and the one above the line represents USS Samuel Gompers (AD-37). Some of the apparent disparity in performance may represent plain-old better service, although such a huge difference seems unlikely. Another explanation for the results can be found in the Fiscal Year 1991

operating schedules of the two ships. USS Cape Cod was deployed to the Persian Gulf from February 1991 to May 1991, during Operation Desert Storm. Due to the nature of the operations in the Persian Gulf, ships were not made available for routine work availabilities and thus USS Cape Cod did not expend the usual number of labor hours on customers. Also, USS Cape Cod was underway for 93 days of the year, an unusually high number for a tender. USS Samuel Gompers, on the other hand, arrived in the Persian Gulf in May 1991, just as USS Cape Cod was returning to San Diego, and remained until August 1991. Many of the ships that had postponed routine intermediate maintenance availabilities were now made available for work and USS Samuel Gompers had more than the usual amount of work requests to accomplish. USS Samuel Gompers also had fewer underway days than USS Cape Cod, accumulating only 72 underway days during the year.

This explanation of the performance differences of the USS Cape Cod and USS Samuel Gompers is a good example of how measurement data should be used. Measurements from all eleven IMAs were looked at, but only the extraordinary cases required additional investigation and explanation.

VI. SUGGESTED MEASURE OF EFFECTIVENESS

The Intermediate Maintenance Activity (IMA) performance measures discussed in Chapters IV and V address efficiency and quantity. The measures are presented in existing reports or can be calculated from data in those reports. Although the Maintenance Resource Management System (MRMS) and the Monthly IMA Utilization Report provide a lot of information, there is still very little information available about IMA *effectiveness*. This chapter will propose some measures of effectiveness (MOEs) for Intermediate Maintenance Activities.

Although it is most appropriate to determine measures of effectiveness first, before efficiency and quantity measures, effectiveness measures are presented last in this thesis. This is because the measures presented in this chapter are not currently collected by COMNAVSURFPAC officials. Measurement data from currently collected reports were examined first for their usefulness in measuring effectiveness. After it was determined that additional measures of effectiveness would be desirable, this chapter was prepared to propose some MOEs to augment the performance data already collected by COMNAVSURFPAC officials.

A. DISCUSSION

The first difficulty encountered when trying to measure effectiveness is defining effectiveness in the context of Intermediate Maintenance Activity (IMA) performance. What is an effective IMA?

Because ship maintenance is a service provided to customer ships by the Intermediate Maintenance Activity, it is appropriate to include the customer in the definition of IMA effectiveness. What is it that the ships receiving maintenance want? When discussing the issue of IMA effectiveness with maintenance providers and maintenance customers, two things are mentioned repeatedly as desirable traits for IMAs: high quality work and timely response to work requests. That is, an effective IMA is one that demonstrates willingness to do work, does the work quickly, and does the work well.

Measuring quality of work is beyond the scope of this thesis. A measure of timeliness that captures some essence of IMA responsiveness is defined below.

B. SELECTION OF APPROPRIATE TIME INTERVAL

The aspect of effectiveness to be measured is timeliness. Effectiveness can be defined in absolute or relative terms. A relatively "more effective" IMA is defined as one that does more work faster than another IMA. An absolute definition of "effective" could be a certain percentage of jobs completed in a certain number of days. For example, absolute effectiveness could be defined as 70% of jobs completed in 180 days or less. The specific time interval used is defined below.

Three different time intervals were considered to represent the effectiveness of Intermediate Maintenance Activities. Two were discarded as inappropriate. The third was selected even though it has some drawbacks.

The first time interval considered was the time between when an IMA started a job and when the IMA finished the job. This would measure something primarily within the control of the IMA but has the same problem of merely counting the number of work requests completed. It only considers the work the IMA does, not the work it chooses not to do. It doesn't take into account that the customer ship may have been waiting for many months to get an IMA to say yes to the job, and then to finally start the job.

The second time interval considered was the time that a job stays on a ship's worklist. The time interval would be measured from the date the ship's personnel put the work request on the worklist to the date of completion of the work request by the IMA workers. The mean-time-on-the-job-list would be calculated for all work requests for each ship. This does assume that the jobs eventually get done because the time interval cannot be calculated until the job is completed. If the ships in a particular homeport had shorter mean-time-on-the-job-list, the IMAs in that port would be defined as more effective than IMAs in other ports. This idea won't work as a measure of *IMA* effectiveness because it doesn't identify individual Intermediate Maintenance Activity performance. Each ship could be served by many different IMAs and so the mean-time-on-the-job-list for a particular ship would be more a measure of the individual ship's effectiveness in using the maintenance system than a measure of IMA effectiveness.

The second time interval described above *can* be used as a measure of IMA effectiveness if the work requests are grouped by which IMA completes the work requests rather than by which ship submitted the work requests. The time interval is measured from the date a work request is put on the ship's worklist to the date the work request is completed by IMA personnel. The time interval will be named Δ and is used to calculate two measures of effectiveness (MOEs) described as follows.

First select the group of work requests to be used to calculate the MOEs. The group can be all the work requests completed by an IMA in any given time period, for example, a quarter or a year or a period of several years. Next determine Δ for each work request where

$$\Delta = \textit{date completed - date identified by ship.}$$

The measures of effectiveness are

$\mathbf{T_p}$ = number of days, Δ, such that p percent of work requests in the group considered have $\Delta \leq \mathbf{T_p}$, and

$\mathbf{P_t}$ = percent of work requests in the group considered that have $\Delta \leq$ t.

The two measures of effectiveness are related to one another as follows:

$$P_{(T_x)} = x, \textit{ and}$$

$$T_{(P_x)} = x.$$

For example, consider $\mathbf{T_{10}} = 25$. It follows from the definition that $\mathbf{P_{25}} = 10$. The percentage of jobs completed in 25 days or less, $\mathbf{P_{25}}$, is 10. The number of days required

to complete 10% of the jobs, T_{10}, is 25. Next consider $P_{30} = 12.8$. It follows from the definition that $T_{12.8} = 30$. The number of days to complete 12.8% of the jobs, $T_{12.8}$, is 30. The percentage of jobs completed in 30 days or less, P_{30}, is 12.8. Defining both T_p and P_t allows the user to emphasize one of two things by selecting the most appropriate measure. Using P_t, the percentage of work completed in a certain time t is emphasized. If it is desired to emphasize how long it takes to do a certain percentage of work p, T_p can be used.

These are compromise measures of effectiveness that have good points and bad points. The good point is that the measures do capture the essence of timely response to customer ship maintenance needs. It measures how long the ship is waiting to get something done.

The bad point about the timeliness MOEs is that not all of the time interval Δ is under the control of the IMA. Both T_p and P_t depend on how well the maintenance system as a whole is working. Part of the wait may be unavoidable. The ship continually identifies problems and places work requests on its worklist even if it is deployed and knows it will be several weeks before it has a maintenance availability.

Some other factors influencing the length of the time interval Δ are:

- Accuracy of information provided by ship,
- Responsiveness of screening authority to task IMA,
- Speed of planning department at IMA,
- Making ship available for work (schedule),

- Doing the work, and
- Completing paperwork.

It is important to remember that some portion of these delays is an acceptable and understood part of the time interval Δ. An MOE doesn't have to be a "perfect", just "appropriate". An MOE is not designed to assign blame or accuse an IMA of dereliction of duty. Rather, it must capture enough of the trait of interest to be helpful in monitoring performance and identifying potential improvements. If numbers come out other than expected, or there is something odd, further investigation is indicated. Remember, measures of performance should be used to identify departure from the acceptable norm. They are supposed to be a method to indicate ways for performance improvement.

A measure of effectiveness is something that should change if additional resources are added, demands are reduced, or procedures are improved. $\mathbf{T_p}$ and $\mathbf{P_t}$ meet these criteria.

C. RESULTS

The two measures of effectiveness, $\mathbf{T_p}$ and $\mathbf{P_t}$, were calculated using data provided by the Naval Sea Logistics Center. The necessary data about all work requests completed by the IMAs in 1990 and 1991 were extracted from the Maintenance Material Management (3M) System Central Data Bank. Data for jobs completed by SIMA Puget Sound, NAB Coronado, and SIMA San Francisco were not available. The time interval

Δ was calculated for each job. Then T_p and P_t were calculated treating the two years of data as one group. Tables 12 and 13 display the results.

TABLE 12

MEASURE OF EFFECTIVENESS T_p
FOR INTERMEDIATE MAINTENANCE ACTIVITIES

	AC	CC	GOM	JA	PR	LB	PH	SD
T_{10}	34	23	13	23	18	39	28	25
T_{20}	56	32	22	40	32	72	49	43
T_{30}	79	55	35	56	49	105	69	60
T_{40}	105	77	52	74	70	138	92	81
T_{50}	129	101	72	95	94	173	119	105
T_{60}	154	138	97	120	124	216	155	134
T_{70}	204	174	131	152	163	279	204	174
T_{80}	243	231	184	203	228	361	292	234
T_{90}	372	312	281	323	354	469	418	350
T_{99}	952	858	720	703	840	920	951	793

TABLE 13

MEASURE OF EFFECTIVENESS P_t
FOR INTERMEDIATE MAINTENANCE ACTIVITIES

	AC	CC	GOM	JA	PR	LB	PH	SD
P_{30}	9.2	18.3	26.4	14.4	18.8	7.4	10.6	12.8
P_{90}	33.4	46.3	57.8	48.5	48.4	25.2	39.4	43.8
P_{120}	45.9	57.3	67.3	60.3	58.7	34.9	50.3	55.8
P_{180}	66.3	72.9	79.4	76.3	73.1	51.5	66.3	71.3
P_{270}	83.7	85.8	89.3	86.9	83.5	68.4	77.8	83.9
P_{360}	89.4	91.7	93.6	92.2	90.7	79.9	86.4	90.7

1. Comparison of Empirical Distribution Functions of Δ

Before individual values of T_p and P_t are examined, the question of statistical significance of the differences in those measures is addressed. Both measures describe the empirical distribution function (EDF) of the time intervals Δ for a particular Intermediate Maintenance Activity. The measures will differ in a statistically significant way only if the empirical distribution functions are different. The Kolmogorov-Smirnov (K-S) Two-Sample Test was used to compare the EDFs [Ref. 18]. At significance level 0.05, the K-S test rejects the null hypothesis that the EDFs are the same in 24 of 28 possible combinations of two IMAs. This means that in almost all cases the empirical distribution functions of the Δs do differ significantly from one another, indicating that differences in T_p and P_t are statistically significant. The cases where the null hypothesis

can not be rejected are USS Acadia/SIMA Pearl Harbor, USS Jason/USS Cape Cod, USS Prairie/USS Cape Cod, and SIMA San Diego/USS Cape Cod.

2. Discussion of T_p

The USS Samuel Gompers (AD-37) has the smallest values of T_p and SIMA Long Beach has the largest values of T_p. T_{50} for USS Samuel Gompers is 72 and T_{50} for SIMA Long Beach is 173. This means that 50% of the work requests completed by USS Samuel Gompers were identified by the customer ships less than or equal to 72 days prior to completion, and 50% of the work requests completed by SIMA Long Beach were identified less than or equal to 173 days prior to completion.

The existence of the difference, although not its magnitude, makes sense because of the differences in how SIMAs and Tenders operate. Tenders are expected to react to short notice work requests, especially while deployed. Often when the tenders are deployed, they will be the only repair facility in the area and may have few customers to service. The tender may ask the customer ships to identify additional work during the availabilities to more fully load the repair workcenters.

The SIMAs, in contrast, are more dependent on long-term planning and scheduling of work. As fixed facilities serving many customer ships, they are often unable to accept additional work identified after the availability work package has been specified. Because the work packages must be submitted several weeks in advance, it is not unreasonable that the SIMAs have higher values for T_p.

Four of the tenders show similar values of T_p, all lower than the T_p values of the SIMAs. USS Acadia is an exception, showing T_p values that look more like the SIMA values.

Again, this MOE is merely an indicator of performance. The MOE itself does not explain why the differences between IMAs occur. Values that stand out from the others must be investigated further to be explained.

3. Discussion of P_t

Another way of examining the timeliness of work request completion by Intermediate Maintenance Activities is P_t. Current Pacific Fleet policy is to schedule each ship for an intermediate maintenance availability once per quarter. If many jobs have $\Delta > 90$ days, that is, P_{90} is small, it indicates that either ships are not being scheduled for availabilities quarterly, as desired, and/or the Intermediate Maintenance Activities are not completing all of the outstanding jobs during the availabilities. Thus, many work requests are carried on the ships' worklists from one availability to another until finally there is an opportunity for an IMA to complete the work request.

Note that SIMA Long Beach has the lowest values for P_t and USS Samuel Gompers has the highest values for P_t. P_{90} for USS Samuel Gompers is 57.8 and P_{90} for SIMA Long Beach is 25.2. Only 25.2% of the work requests completed by SIMA Long Beach were identified less than or equal to 90 days prior to completion, while 57.8% is the proportion for USS Samuel Gompers.

Since no IMA has a P_{90} greater than 57.8, it appears that a large number of work requests linger on ships' worklists for long periods of time. Some of the time

delay may be due to ship operating schedules, backlog of work requests caused by insufficient IMA capacity, or failure of ships' personnel to properly use the maintenance system. Again, The measure of effectiveness, $\mathbf{P}_t$, is only an indicator of performance. Explanations as to why the values are what they are must be discovered through further investigation.

D. SUMMARY

The two measures of effectiveness, $\mathbf{T}_p$ and $\mathbf{P}_t$, provide information about the timeliness of Intermediate Maintenance Activity response to work requests. They can be used to identify and correct impediments to a faster turnaround time for completion of work requests by focusing the attention of COMNAVSURFPAC officials on the IMAs that are performing poorly. Collected over several periods of time, $\mathbf{T}_p$ and $\mathbf{P}_t$ can be used to monitor trends in performance.

VII. CONCLUSIONS AND RECOMMENDATIONS

This thesis has examined various performance measures for ship Intermediate Maintenance Activities. Performance measures are currently collected for quantity, efficiency, and productivity Effectiveness is not currently measured, but can be measured as recommended in Chapter VI. All of the measures provide some information about IMA performance and can be used by Naval Surface Force Pacific officials to monitor IMA performance. However, two things must be carefully considered by users of the performance measures to avoid erroneous conclusions.

First, understanding the definitions of what is being measured and what units are being used is critical. Second, statistical tests are necessary to say with confidence that the performance of IMAs differ. Many of the differences in performance measures are not statistically significant.

No one performance measure can quantify all aspects of IMA performance. Even all of them together do not tell the whole story of IMA performance. As Moore warns,

> Beware the arrogance that says that everything can be measured, or that only things we can measure are important. The world contains much that is beyond the grasp of statistics. [Ref. 10]

There are intangibles of Intermediate Maintenance Activity performance that will augment measurement data when IMA performance is evaluated.

Recommendations for further study can be grouped as additional research in support of existing performance measures, and as additional ideas for measuring effectiveness.

It was shown in Chapter V that, on average, 97.59 manhours were expended on customers per direct repair production worker per month. It is unknown if this is a reasonable or acceptable amount. A study should be done to discover how many manhours per worker are actually available for productive work after all mandatory Navy programs are completed. Such things as mandatory safety training, career counseling, equipment maintenance, and other duties reduce the number of manhours available to expend on customers. Perhaps the 97.59 customer manhours is close to what is actually available to expend on customers.

More ways to measure effectiveness, in addition to $\mathbf{T}_p$ and $\mathbf{P}_t$ recommended in Chapter VI, should be developed. A potentially successful method is a customer satisfaction survey. A scientifically designed and analyzed survey of customer ships, taken at regular intervals, would give valuable information about the effectiveness of IMA performance.

Both proper use of measurement data and concern for customer satisfaction are elements of Total Quality Management (TQM), a management philosophy being embraced by the United States Navy. One author summarizes the key elements of TQM as follows:

> The pillars of the cultural change are: focus on customers (both internal and external); data-driven continuous improvement; and new ways to involve employees and management in joint identification and solution of problems. [Ref. 21]

Measurement pervades Total Quality Management and is critical to its success. The discussion presented in this thesis points out facts and concerns about performance measurement to be addressed whether or not TQM is implemented at ship Intermediate Maintenance Activities.

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